

pattern. Namely, the areas of the substrate not to be covered by the electrodes is covered by a photoresist. After metal deposition, the photoresist is dissolved in an acetone bath, leaving the electrodes covering the desired areas of the substrate. This allows the electrodes to be formed in the desired pattern without post deposition etching steps. In other embodiments according to the present invention, the substrate can comprise a printed circuit board.

[0031] A fluid (medium) 44 at least partially fills each of the cylinders 32, 34 with the fluid preferably filling substantially all of the cylinders 32, 34. Many different fluids can be used to fill the cylinders 32, 34 with preferred material being air or one or more phase change materials alone or in combination with other materials. A suitable phase change material is a paraffin wax that can include one or more paraffins. In the embodiment having a mixture of paraffins, the mixture can include n-paraffins, iso-paraffins and cyclo-paraffins, with n-paraffins typically being the predominant type. Paraffins used in the present can have a melting point range of approximately 10° C. or less. In certain cases, the melting point range is 5° C. or less, 4° C. or less, 3° C. or less or even 2° C. or less.

[0032] Paraffins used in the present invention typically begin melting above 35° C. Often times, they begin melting above 40° C., 50° C., or 60° C., 70° C. or higher. The use of paraffins including ≥ 90 percent of the same compound can be desirable. In some embodiments the use of paraffins including ≥ 95 percent of the same compound or ≥ 97 percent of the same compound is desirable. Paraffins used in the present invention may optionally include one or more antioxidants. A non limiting list of such antioxidants includes: vitamin E; vitamin C; BHA; and, BHT. Typically, the antioxidants are included at a weight/weight percentage of 1 percent or less. The Paraffin wax embodiment can be injected into the cylinders in its liquid state using known injection methods.

[0033] The membrane 38 is shown with separate membrane sections covering the top openings of the cylinders 32, 34. In other embodiments, the membrane can be one single piece covering the cylinder openings as well as the chamber wall mesas 46 as shown in phantom. As described above, the membrane is preferably made of flexible material having a low Young's modulus such as commercially available silicone and BCB (Cyclotene from Dow® Chemical). The membrane can be bonded in place over the cylinders using known bonding methods, such as spin coating.

[0034] The chamber wall and the substrate are preferably made of materials having low heat conductivity and are electrically insulating. Many different materials can be used such as glass, plastics, semiconductors and some ceramics. Silicon is also a suitable material in that microfabrication using silicon has been developed that can be applied to the present invention. In one embodiment using silicon, the chamber walls 36 are provided as a single wafer that can then be etched by DRIE (Bosch etch) to form the cylinder openings. For glass, etching processes can also be used, although it may be difficult to form straight chamber walls etching from glass. Cylinders can be formed in plastic using known fabrication methods. In still other embodiments the chamber wall and substrate can be made of a polymer, such as polycarbonate or PMMA. Alternatively, a thick photoresist, such as commercially available SU-8 can be used and

photo-patterned to form the cylinders 32, 34. It is understood that many different materials can be used, and the cylinders can be formed in the materials using many different methods.

[0035] The cylinders 32, 34 can have many different diameters, with a suitable diameter being between 1.0 mm and 1.9 mm. Preferred cylinder diameters are between 1.4 and 1.6 mm, which correspond to the common dot base diameters for English based Braille cells. The cylinders can also have different depths, with a suitable depth being approximately 500 μ m.

[0036] The substrate 42 can be made of many known materials, such as silicon, and can have conductive traces formed thereon using known methods. The traces conduct electrical signals to the electrodes (microheater) 40. The structure (wafer) forming the chamber walls 36 can be bonded to the substrate 42 by a bonding layer 48. The bonding layer can be a polymer adhesive, such as BCB (Dow® Chemical) or Overglaz (QQ 550, Dupont® Company). If the chamber wall wafer and/or substrate are made of glass, they can be bonded together using fusion bonding. If either or both are made of a photoresist or plastic, direct bonding methods can be used. It should be understood that the bonding method depends on the type of material selected for the substrate and chamber walls.

[0037] As shown, chamber 32 is not actuated. That is, its electrode 40 is not generating heat such that its fluid 44 is not expanding. Chamber 34, on the other hand, is actuated. Its electrode is being energized by an electrical signal to heat its fluid. This causes the fluid to expand and the membrane 38 to bulge over the cylinder opening. The desired membrane bulge is actuated by controlling which electrode is energized. The desired electrodes can be energized using known methods, with the electrodes 40 deposited on the substrate 42 with interconnecting traces to allow each electrode to be separately energized. This type of electrode and trace interconnection is known.

[0038] FIG. 3a shows a sectional view of one embodiment of three Braille cells 60 according to the present invention arranged in a line. Each Braille cell typically comprises six (6) cylinders 62, although only two cylinders in each cell are shown. A continuous membrane 64 covers the cylinders. Within each cell, space 66 between cylinders 62 as shown is typically between 2.03 and 3.25 mm, although other spaces can also be used. Preferred horizontal spaces within a cell are between 2.2 and 2.54 mm. The space between adjacent Braille cells in a line 68 is typically between 2.5 mm and 6.53 mm, with the preferred space between cells being between 3.81 mm and 5.42 mm.

[0039] FIG. 3b shows a sectional view of two Braille cells 80 according to the present invention that are arranged in two different lines. A continuous membrane 82 again covers the cylinders 84. Spaces 86 between the dots within a Braille cell are approximately the same dimensions as spaces 66 in FIG. 3a. The space 88 between adjacent Braille cells are approximately the same dimensions as spaces 68 in FIG. 3a.

[0040] FIG. 4 shows one embodiment of three Braille cells 90, 92, 94 having cylinders that have been actuated to bulge the desired membrane. On dot (bulged membrane) appears in cell 92, which corresponds to the letter "a"; four dots appear in cell 94, which correspond to the letter "n"; and,